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Number of Galactic Civilizations

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Abstract: A probabilistic assessment is made to determine the likely range of galactic civilizations. In order to define the possible number of advanced galactic civilizations, the number of habitable planets is being determined with the help of a newly formulated probability equation. This equation is expressing the number of habitable planets in terms of the assumed galaxy size, the number of critical habitability criteria and the star and planet compliance rates with these criteria. For effectiveness the equation uses instead of the individual compliance rates with the various habitability criteria the geometric mean of the compliance rates with the criteria. This simplifies the calculational approach considerably and makes it possible to obtain the necessary data to assess the extent of galactic habitability. These data are included in a Galactic Habitability Table which presents in this way a complete overview of galactic habitability of a given galaxy as a function of the number of critical criteria and the mean compliance rate with these criteria. While no scientific certainty exists at present time for the exact values of these two parameters, zones of high probability can already be assessed. For any number of habitability criteria assumed a minimum star and planet compliance ratio can be determined which is required for the existence of advanced civilizations in a galaxy of any given size. As the next step the issue of concurrent communicating civilizations has also been addressed.

Keywords: Galactic Habitability, Milky Way Galaxy Habitability, Planet Habitability, Galactic Civilizations, Drake Equation.

1. INTRODUCTION

The number of communicating intelligent civilizations a galaxy may contain has been justifiably of long standing interest. Are we alone in our part of the world, in the realm of the Milky Way Galaxy or are we in the company of possibly some or may be even many advanced civilizations. Could these be reached by two-way communication? How about advanced civilizations in the rest of the many other galaxies. An evaluation of the number of advanced civilizations in the galaxy has already been attempted in 1961 with the Drake probability equation, Strachan [1] Drake [2].

As it turned out the assessment of the various factors involved can vary broadly and therefore no distinctive conclusions have been reached.

In order to clarify this issue further it has been attempted here to express the probability equation, defining the number of habitable planets, in terms of the number of planet habitability criteria and the mean star and planet compliance rates with these criteria.

This presentation provides an overview of how potential variations in the number of habitability criteria will impact the possible number of habitable planets with advanced civilizations under conditions of different star and planet compliance rates with the stated criteria.

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While the number of critical habitability criteria is not yet precisely known the effect of an increase or decrease in this number can be readily assessed.

For any number of habitability criteria assumed a minimum star and planet compliance ratio will be determined which is required for the existence of advanced civilizations in a galaxy of any given size. Further the issue of concurrent communicating civilizations will also be addressed.

2. CALCULATIONAL METHOD

The planet habitability equation is expressed in terms of the number of habitability criteria and the star and planet compliance rates with these criteria. The compliance rate is expressed as the geometric mean of the product of the individual compliance rates associated whith each habitability criterion.

Ph is the number of habitable planets with advanced civilizations

Sg corresponds to the number of stars in the galaxy

n is the number of star and planet habitability criteria

C1 to **Cn** represent the rate of stars and planets meeting the required habitability criteria.

$$\mathbf{Ph = Sg\ x\ (C1xC2xC3...\ xCn)} \quad (1)$$

C is the geometric mean of the product **C1** to **Cn**

$$\mathbf{C = (C1xC2xC3\ldots\ xCn)^{1/n}} \quad (2)$$

$$\mathbf{Ph = SgxC^{n}} \quad (3)$$

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Table 1. Minimum Compliance Ratio for Galaxy Habitability

Criteria (n)	Ratio Of Compliant Stars and Planets (C)
20	1/3.67
16	1/5.08
15	1/5.67
14	1/6.42
13	1/7.40
12	1/8.75
11	1/10.65
10	1/13.49
9	1/18.01
8	1/ 25.86

Note. Ph = $(200x10^9)xC^n = 1$

Substantial research has been done to define the planet habitability criteria by Ward *et al*. [3], Tarter *et al*. [4], Ulmschneider [5], Kasting [6] and numerous others.

To illustrate the calculational method presented we will use an example where we assume that there are 11 key habitability criteria in order for a planet to have an advanced civilization capable of communications.

These criteria could possibly be defined as

1. Location of the star in the Galaxy habitability zone
2. Suitable star
3. Planet located in the star habitability zone
4. Planet of proper size
5. Planet with rocky geology and water
6. Planet having magma
7. Planet with proper orbit
8. Proper orientation
9. Proper speed of rotation
10. Proper atmosphere
11. Evolution from primitive life forms to intelligent life

The calculations assume a galaxy having 200 billion stars.

Two calculations will be made to illustrate the method indicated. In the first calculation there is assumed a 1 in 10 geometric mean compliance rate with the above criteria.

$\mathbf{C} = 1/10$

$$\mathbf{Ph1} = (200x10^9)x(1/10^{11}) = 2 \quad (4)$$

This is a galaxy having during its "fertile" period 2 planets with advanced civilizations.

In the next calculation it is considered that in average 1 out of every 5 stars and planets comply with the specific habitability requirements $\mathbf{C} = 1/5$

$$\mathbf{Ph2} = (200x10^9) \times (1/5^{11}) = 4{,}096 \quad (5)$$

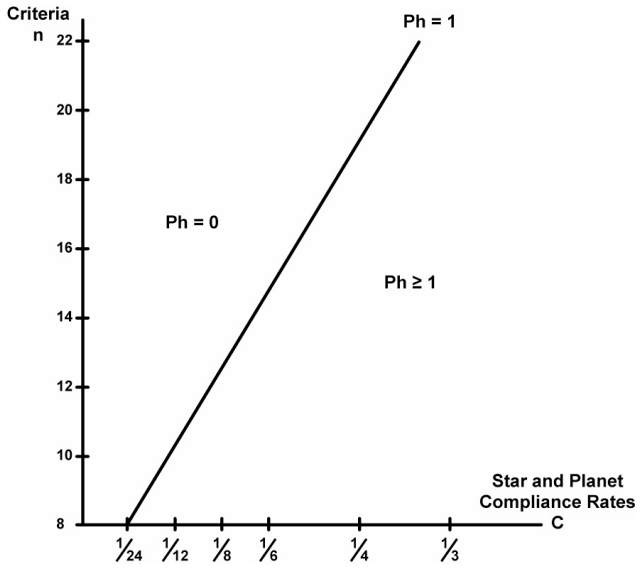

Fig. (1). Galaxy habitability dividing line separating the habitable domain from the inhabitable one in case of a 200 billion star galaxy.

In this case 4,096 planets will have advanced civilizations The number of habitable planets with advanced civilizations can be prorated for galaxies of different magnitudes. In case of a galaxy with 100 billion stars Ph1 becomes 1 based on Eq. (4) while Ph2 is 2048 based on Eq. (5).

In the case of a galaxy with 500 billion stars Ph1 is 5 and Ph2 becomes 10,240 The above calculations make it clear that whatever the number of habitability criteria would be there is a minimal ratio of complying stars and planets required to reach the value of Ph = 1 and assure the habitability of a galaxy.

Table **1** contains the result of this determination.

It allows us to establish a curve delineating the borderline, which separates the habitable zone from the inhabitable zone of a galaxy assuming different numbers of mandatory habitability criteria.

The given example is based on a galaxy with 200 billion stars.

It provides the geometric mean ratio of compliant stars and planets required for a Ph of 1 corresponding to one advanced civilization per galaxy.

C is the geometric mean in conformance with Eq. (2)

In case if the ratio of compliant stars and planets is greater than the above values, whenever a value of Ph=2 or greater is attained, multiple advanced civilizations become possible.

In case of smaller compliance ratios than those listed in Table **1**, advanced civilizations would not materialize in the given galaxy.

Obviously in our galaxy the proper compliance rate has been obtained and is probably exceeded.

A graph in Fig. (**1**) illustrates the dividing line separating the inhabitable domain of a galaxy with 200 billion stars from the habitable one having one or multiple advanced civilizations.

Table 2. Galactic Habitability Table (Ph)

Criteria (n)	Star and Planet Compliance Rate (C)						
	1/4	**1/5**	**1/6**	**1/7**	**1/8**	**1/9**	**1/10**
16	46	1	---	---	---	---	---
15	186	6	---	---	---	---	---
14	745	32	2	---	---	---	---
13	2980	163	15	2	---	---	---
12	11980	819	91	14	2	---	---
11	47683	4096	551	101	23	6	2
10	190734	20480	3307	708	186	57	20
9	762939	102400	19845	4956	1490	516	200
8	3051757	512000	119074	34693	11920	4646	2000

Note. The number of habitable planets (Ph) is determined in accordance with Eq. (3) The Table is made for a Galaxy of 200 billion stars and can be extended for any geometric mean compliance rates as well as prorated for other galaxies.

To explore the possible number of advanced civilizations in our galaxy, Table **2**. is being provided for a galaxy with 200 billion stars showing the number of habitable planets with advanced civilizations for a range of critical criteria and diverse star and planet geometric mean compliance rates.

Fig. (**2**) shows the variation in the number of Habitable Planets (Ph) as a function of the Star and Planet Compliance Rates for the case of three different Habitability Criteria (n) values.

Table **3** and Fig. (**3**) show the Star and Planet Compliance Rates (C) needed to obtain a predetermined number of Habitable Planets (Ph). (C) is based on Eq.(3). Gs is 200 billions.

3. CONCURRENT CIVILIZATIONS

While the number of habitable planets could be considerable in cases of high geometric mean compliance rates, for instance 47683 in case of 11 critical criteria and a compliance rate of 1/4, due to the assumed relative shortness of the expected life span of advanced civilizations the number of super positions of these civilizations at a given time will be considerably limited.

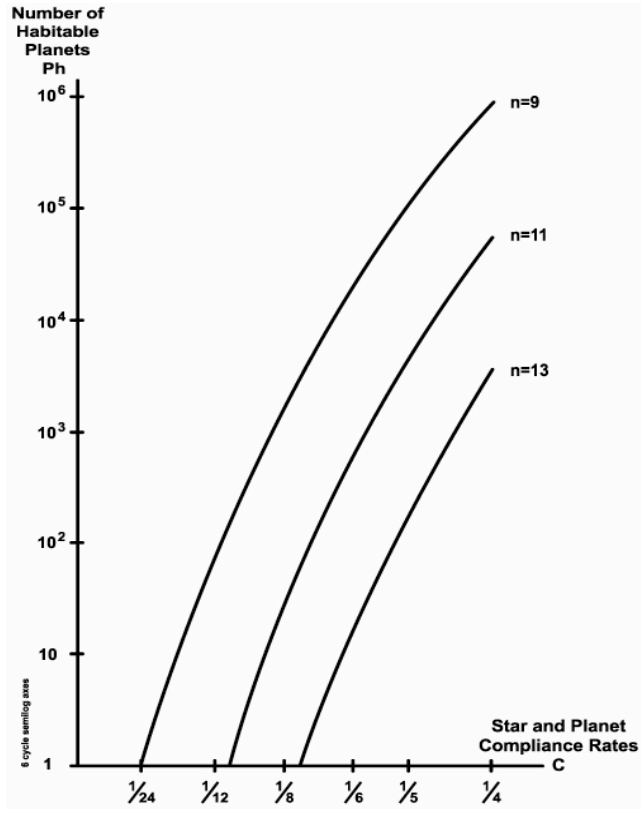

Fig. (2). Number of Habitable Planets (Ph) in accordance with Eq. (3), as a function of Star and Planet Compliance Rates (C) for the case of 9, 11 and 13 Habitability Criteria (n). The number of stars Gs is 200 billions.

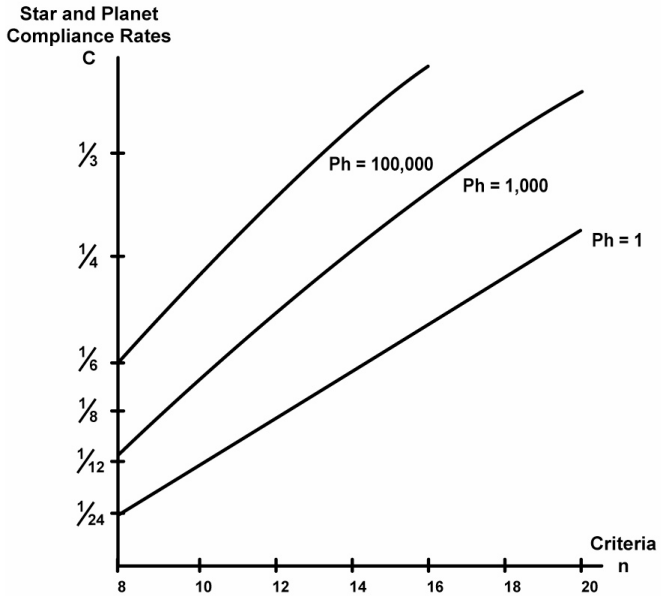

Fig. (3). Star and Planet Compliance Rates (C) function of the number of Habitability Criteria (n) for groups of Habitable Planets (Ph) of different magnitudes.

Table 3. Shows the Star and Planet Compliance Rates (C) Required to Obtain a Certain Number of Habitable Planets (Ph) for Different Numbers of Habitability Criteria (n)

Criteria (n)	Number Of Habitable Planets (Ph)		
	1	**1000**	**100,000**
20	1/3.67	1/2.60	1/2.06
16	1/5.08	1/3.30	1/2.47
15	1/5.67	1/3.57	1/2.63
14	1/6.42	1/3.91	1/2.81
13	1/7.40	1/4.35	1/3.05
12	1/8.75	1/4.92	1/3.35
11	1/10.65	1/5.68	1/3.74
10	1/13.49	1/6.76	1/4.26
9	1/18.01	1/8.36	1/5.01
8	1/25.86	1/10.91	1/6.13

Table 4. Number of Habitable Planets (Ph) Required for Sequential Civilizations Over Gt

Duration of Civilizations (Lc)	Number Of Concurrent Sequential Civilizations (Sc)		
Years	**1**	**10**	**100**
1,000	$5x10^6$	$5x10^7$	$5x10^8$
10,000	$5x10^5$	$5x10^6$	$5x10^7$
100,000	$5x10^4$	$5x10^5$	$5x10^6$
1,000,000	$5x10^3$	$5x10^4$	$5x10^5$

Note. Where Gt = $5x10^9$ years. Number of Habitable Planets results from Eq. (6) Outcome can be prorated for other Gt durations.

Let us define

Lc as the average life span of an advanced civilization in years

Gt as the suitable period in the existence of a galaxy when advanced civilizations can occur

Ph is the number of habitable planets with advanced civilizations

Sc is the number of concurrent sequential civilizations for the duration of Gt

The civilizations are assumed to follow consecutively for the entire favorable duration of the galaxy.

We will determine Sc assuming Gt of 5 billion years and Lc as different durations from 1,000 to 1,000,000 years.

$$\mathbf{Sc = (PhxLc)/Gt = SgC^nLc/Gt} \quad (6)$$

Let us consider two more extreme situations assuming 11 critical criteria.

In the case of Ph = 2 corresponding to a compliance rate of 1/10 concurrent civilizations are not likely.

For Ph = 47,683 corresponding to a compliance rate of 1/4 and

$$Lc = 1{,}000 \;\; Sc = (47{,}683x1{,}000)/(5x10^9) = 0.0095 \quad (7)$$

$$Lc = 10{,}000 \; Sc = (47{,}683x10{,}000)/(5x10^9) = 0.0953 \quad (8)$$

$$Lc = 100{,}000 \; Sc = (47{,}683x100.000)/(5x10^9) = 0.9536 \quad (9)$$

$$Lc = 1{,}000{,}000 \; Sc = (47{,}683x1{,}000{,}000)/(5x10^9) = 9.5360 \quad (10)$$

In a more remote case like the case defined in (10), where 1,000,000 year lifespans are assumed for the civilizations and assuming that these civilizations are running successively, there would be a concurrence of 9 to 10 advanced civilizations at any given time.

In case of likely additional super-positions due to imperfect sequences as well as some planets having multiple civilizations in the course of their existence, assuming a peak to average ratio of 10 to 15, this may lead to a possible peak in the range of fewer than hundred to possibly over hundred concurrent advanced civilizations over limited time periods.

Much lower concurrence of civilizations exists in the other described cases (7), (8) and (9) by factors of 1000 to 10 which could bring about occasional periods without any advanced civilization in the galaxy.

These calculations indicate that the superposition in time of advanced civilizations on the various habitable planets will be extremely limited which greatly reduces the possibility of interplanetary communications with other advanced civilizations.

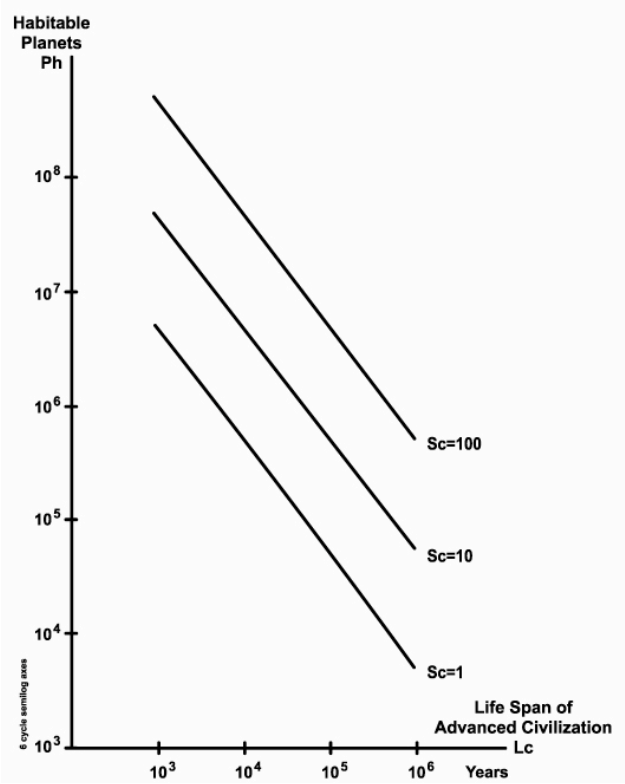

Fig. (4). Number of Habitable Planets (Ph) needed to assure one or more full Sequences of Advanced Civilizations during the useful lifetime of a Galaxy (Gs).

Table **4** provides the number of Habitable Planets (Ph) required to allow for 1 to 100 simultaneous sequential civilizations during the useful lifetime of the Galaxy (Gt) and assuming various durations for these advanced civilizations.

Fig. (**4**) shows the correlation between the number of Habitable Planets and the number of concurrent sequential civilizations for different life spans of the advanced civilizations.

4. CONCLUSIONS

Based on the planet habitability equation derived, a probabilistic evaluation has been made to determine the possible number of habitable planets with advanced civilizations within a galaxy corresponding to a range of critical habitability criteria as well as diverse geometric mean star and planet compliance rates. This provides a good overview of the possible range of planets with advanced civilizations which could be encountered in a galaxy in particular when the number of critical habitability criteria is narrowed down to the most probable ones.

The minimum mean star and planet compliance rates for assumptions with differing number of habitability criteria, needed to assure planet habitability with an advanced civilization, has also been determined. As known this limit has been attained and is most probably exceeded in our Milky Way Galaxy. The issue of communicating civilizations has also been examined. Due to the expected limited superposition of advanced communicating civilizations and the great stellar distances involved chances of interplanetary communications appear to be exceedingly tentative.

CONFLICT OF INTEREST

The author confirms that this article content has no conflicts of interest.

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DISCLOSURE STATEMENT

No competing financial interests exist.

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